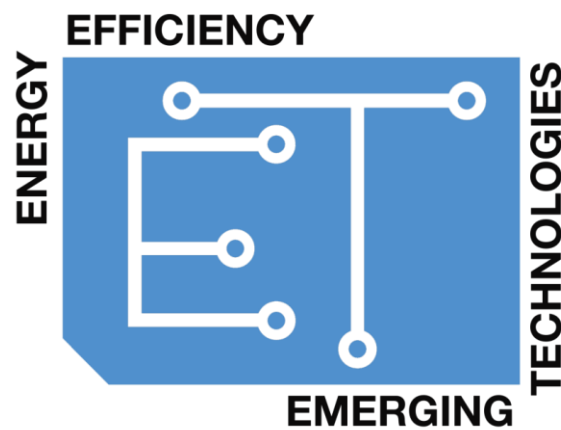


Line Voltage Connected Thermostats

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A Report of BPA's Emerging Technologies Initiative

Prepared for

Bonneville Power Administration

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SUMMARY

BPA is interested in exploring controls for electric resistance zonal heaters as an opportunity for regional efficiency improvements. Zonal electric resistance heat is used in many homes in the Pacific Northwest including multifamily homes. Its popularity is driven by its low first cost compared with other more efficient heating systems, lower price of electricity and reduced need for cooling in the region, and lack of natural gas availability in rural areas.

Most line-voltage thermostats used to control electric resistance heat in the Bonneville Power Administration region are simple bimetallic mechanical thermostats. Preliminary studies show that replacing them with electronic connected line-voltage thermostats (line-voltage connected thermostats) may offer approximately 13% energy savings.

This paper provides an overview of line-voltage thermostats that have connected features to control residential zonal electric resistance (ER) heat in the Pacific Northwest (PNW). It provides background on the various types of thermostats, their energy efficiency potential, non-energy benefits, and key features. Key findings include (1) there are at least 13 line-voltage connected thermostats on the market; (2) the market is introducing new features; (3) there is not much current data on energy savings potential but a conservative estimate is 13%; and (4) more research needs to be completed to determine the savings for single-family and multi-family applications. Based on inferences of energy savings and the number of ER heated homes in the PNW, the estimated regional potential is 120aMW. Payback, without any incentives, appears to be 5.2 years single-family and 8.2 for multifamily.

Supporting adoption of line-voltage connected thermostats through field studies and modeling, engaging thermostat manufacturers, and promoting non-energy benefits, may benefit BPA in their quest for regional energy savings in the ER heating customer segment that has been difficult to reach. Establishing a new BPA incentive for electronic connected line-voltage thermostats would benefit adoption, resulting in increased comfort and savings not only for customers, but also possible peak demand reduction opportunities, project savings validation, and smart grid connectivity for utilities.

BACKGROUND

In 2016, Bonneville Power Administration began exploring controls options for electric resistance heat for single family and multifamily applications. This initiative began with qualitative research to understand what options might be available. Washington State University Energy Program staff was hired to explore line voltage connected thermostat products to understand the available features and market prices. The study involved an extensive literature search to understand makes, models, features and costs of these thermostats. This literature search was augmented with interviews with utility partners and industry experts.

BPA has no current measure specifically for line-voltage connected thermostats for single family and multifamily homes. The current incentive for replacing bimetallic thermostats with electronic thermostats fails to take into account the potential increased energy savings that connected

thermostats can bring. A connected thermostat for zonal ER heat for single family, multi family, and manufactured housing may fill a gap in the current measures.

RESEARCH METHODS

The objective of this research was to gather information on line-voltage thermostats that are able to control zonal ER heat to assess the current technologies and features. To this end, WSU performed an extensive literature search, as well as interviewing staff from utilities, manufacturers, and other organizations. A list of references can be found in Appendix A.

TECHNOLOGY OVERVIEW

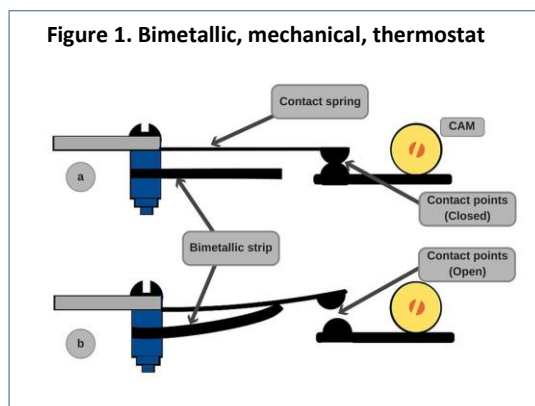
This section provides an overview of the different types of line voltage thermostats. BPA categorizes line-voltage thermostats as bimetallic line-voltage thermostats, electronic line-voltage thermostats, programmable thermostats, connected thermostats, and smart thermostats.¹ The thermostats are listed and described below in order of increasing efficiency. Information includes details about key features and drivers for energy savings. Finally, a brief overview of electric resistance heating systems for residential buildings is included.

Thermostat Definitions²

Naming systems of different types of thermostats used for ER heat have changed over time and are not universally consistent. For example, a smart thermostat was once (and still can be) considered one that is connected to the Internet, yet the prevailing definition is one that is connected and adjusts settings according to external inputs.

Bimetallic Line-voltage thermostats

The baseline for line-voltage thermostats is a bimetallic (mechanical) thermostat used to control zonal electric resistance (ER) heat. One thermostat controls one heating zone. Bimetallic line-voltage thermostats have strips of two metals joined together that expand at different rates when they are heated, causing the strip to bend toward or away from a contact that completes an electric circuit and turns heaters on or off. They have no programming capability and have up to a 6°F deadband³ (see box below).



¹ There is no universal naming protocol for line-voltage thermostats. This paper uses the naming convention that is accepted by BPA's energy efficiency emerging technology program.

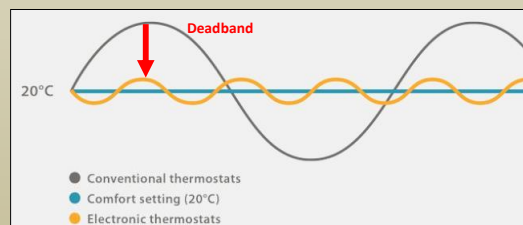
² Electronic low-voltage thermostats are not included in the definitions because they are not generally used for ER heat – they control central furnaces and air conditioners. A low-voltage thermostat may control ER zonal heat, but require a relay to do so, adding cost and complexity. They are powered by 24-volt power and/or AA batteries, the latter having the advantage of being wireless.

³ Deadband is the temperature range between where a thermostat switches on and shuts off a heater.

DEADBAND

All thermostats have a “deadband”, which is the temperature differential (hysteresis) between where a thermostat switches on and off a heater. The length of time between when heat is turned on and off is the control interval. The longer the control interval, the larger the deadband, as seen in Figure 2. Electronic thermostats can switch heaters on and off up to four times per minute. When both a bimetallic and electronic thermostat are set at the same temperature, the ambient room temperature is lower before the bimetallic (conventional) thermostat switches the heat on. The amount of energy used is greater with a larger deadband and longer interval. Occupants often increase the setpoint of a bimetallic thermostat to ensure that the lowest temperature of the deadband is not outside their comfort zone.

Figure 2. Example of Comparison of Thermostat Deadbands



Based on (Hydro Quebec 2017)

Electronic Line-Voltage Thermostats

Electronic line-voltage thermostats use electronic heat sensors and microprocessors instead of metal strips to detect a change in ambient temperature and turn heat on or off accordingly. They work when an electrical current passes through a thermistor (a resistor that measures temperature) in the thermostat, the thermistor heats up, which heats the thermometer coil. This causes the coil to unwind, in turn causing a microcontroller to switch off the heater. When the thermistor and coil cool down, they revert to their original position, and the heater turns on. Electronic thermostats respond much faster to temperature change than bimetallic, allowing for a much smaller deadband, typically around $\pm 1^{\circ}\text{F}$.

Deadband and droop are fundamental in producing greater energy efficiency in electronic thermostats compared to mechanical (bimetallic) thermostats. A smaller deadband effectively reduces the temperature differential between the measured and ambient temperature, resulting in energy savings.

Programmable Thermostats

Preset schedules can be entered into programmable thermostats to maintain specific temperatures at different times of the day,

automatically raising or lowering a home's space temperature dependent on when the occupant thinks, for example, they will wake or go to bed, leave or return home. Some thermostats allow for daily programming, with up to six periods each day. Programmable thermostats reduce energy use by automatically adjusting the temperature according to the schedule set by the user. The most common adjustment is setting the temperature back at night.

Connected Thermostats

Connected thermostats may connect to the Internet via wireless networking, such as Wi-Fi. This allows users to adjust heating settings from other Internet-connected devices, such as smartphones. Connected thermostats can offer online alerts, monitoring, and programming/control from a remote

Internal Heat Compensation - DROOP

Line-voltage thermostats generate enough internal heat to impact their accuracy in sensing room temperature. This is known as “droop,” which can be up to 3°F and even higher with larger heating loads. As the internal heat increases, the thermostat responds to that instead of the actual room temperature, switching the heating system off at a lower room temperature than desired. Mechanical thermostats experience more droop than digital models because of how the metal strips heat up, as well as the longer control intervals. Electronic thermostats that use relays are less susceptible to droop than those that use triacs (a semiconductor device for controlling current) (Burke 2017).

Thermostats need to be able to predict and compensate for the impact from droop by using algorithms and an understanding of the rate of internal heating and cooling. Some manufacturers may better manage droop than others, such as allowing users to adjust the temperature displayed to manually compensate for droop, or developing a droop compensation algorithm (Walker, Temperature Measuring in Smart Controllers 2013).

location. They are also known as “web-enabled”⁴. Energy efficiency with connected thermostats results from the ability to change the temperature setting when away from home. For example, if working late, the user can change the temperature to increase at a later time than originally scheduled.

Smart Thermostats

The key additional feature of a smart thermostat is its ability to communicate with home automation systems and other devices, and use sensors to detect occupancy, occupant routines, weather forecasts, and more. The data gathered through the sensors allows the thermostat to adjust heating and cooling temperature programming accordingly, as well as, in some cases, to learn occupancy patterns and change settings on an ongoing basis.

In addition to the Wi-Fi networking protocol, some thermostats use radio frequency communication (RF)⁵ protocols, such as Z-Wave and ZigBee, to connect to the Internet, central hubs, home automation systems, and other devices. These can be used in addition to, or instead of, Wi-Fi.⁶

⁴ BPA has previously referred to web-enabled programmable thermostats as WEPT, though that label is no longer used.

⁵ One advantage to RF is the ability to avoid interference with Wi-Fi devices. Another is their mesh network that allows each thermostat to act as a signal repeater to others, ensuring a strong signal even in larger homes. RF has short range limits of about 30 feet, although it varies with building materials, e.g. the signal does not penetrate reinforced concrete walls or floors/ceilings well. In addition, RF will not lose connection to a home automation if the Internet connection is lost, as happens with WiFi (Green 2017).

⁶ Further information sharing and activity coordination with other home electronic devices can be accomplished using APIs (application programming interfaces), which allows one application to share data and take actions based on another device’s behalf without requiring developers to share all of their software code. IFTTT (pronounced “ift”), used with or without APIs, creates applets – chains of conditional statements that can transfer information among connected electronic devices, such as Nest (Green 2017).

Thermostat Features

Line-voltage connected thermostats that are connected or smart offer advanced features that increase functionality and comfort for users. While deadband is an inherently energy-saving feature in electronic thermostats, features listed below tend to be controlled by user behavior and habits. Features available in line-voltage connected thermostat products currently on the market are described in this section.

Occupancy Sensing

Sensing whether or not an occupant is home, and adjusting the thermostat settings accordingly, has the potential for increased energy savings. Thermostats can include a built-in occupancy sensor or communicate with other devices that sense occupancy. For example, a product with built-in sensors that requires two thermostats within a five-meter range will set the temperature back when no motion is detected.

Other thermostats may connect to other devices, such as a Nest thermostat, to use their occupancy control capabilities, or use IFTTT communications to connect with devices that sense occupancy. The ability to connect to the Internet and other devices enables programming that makes use of the devices' sensors. For example, by sensing vacancy through these devices, thermostats can override the program to set back the temperature. This provides additional energy savings if done correctly. If not, it can annoy occupants and decrease use and adoption rates.

EXAMPLES OF OCCUPANCY SENSING FEATURES

- Using Nest's occupancy sensor, geolocating, and self-learning programming to determine Home or Away. This allows all heating, including a central HVAC system, to be controlled by Nest.
- Using Fitbit's sleeping state to override programming when its user is sleeping.
- Set back the heat according to Gmail appointments.
- Geofencing which is an invisible boundary set by an app a certain distance from a home defined by an occupant with a smart phone Geographic Positioning System (GPS). If the occupant with the smart phone goes outside the boundary, the line-voltage connected thermostat can, for example, change the thermostat set point to match an "away" setting. This technique is also used to return set points to "home" setting, when the boundary is crossed back over.

Weather reporting

In some cases, a thermostat may be able to program itself based on weather forecasts. For example, sensing temperature and humidity outside of the house, the indoor temperature may be increased to anticipate cold weather, increasing owner comfort.

Machine Learning

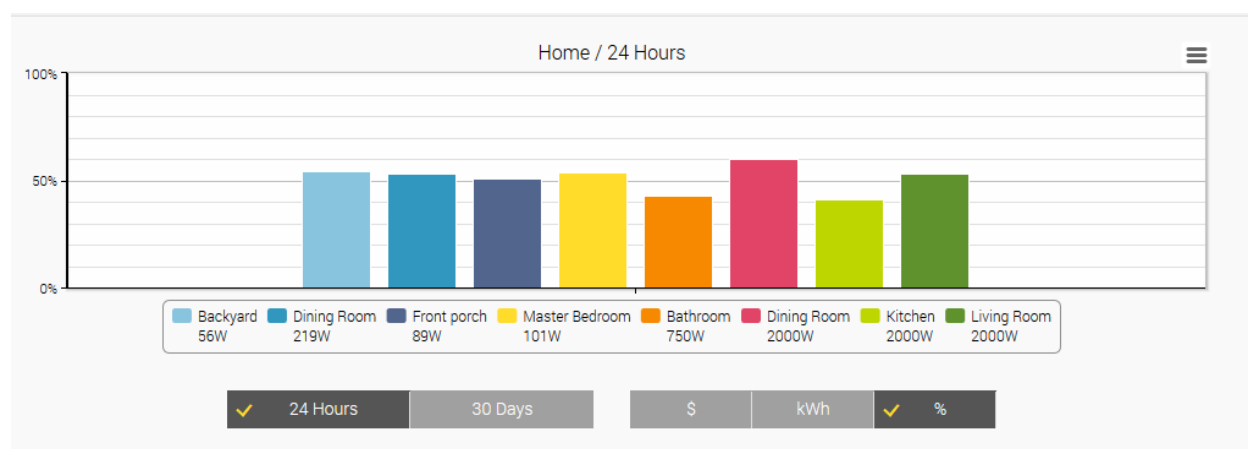
Sophisticated HVAC controls that learn a home's thermal characteristics, capacity of the HVAC system, occupancy patterns, and temperature preferences can use this information to reduce system run time while meeting the comfort needs of occupants. While none of the thermostats studied have machine learning capability as advanced as Nest thermostats, two appear to have some learning capability. Weather data can be used to calculate how long each room takes to warm up such that it can begin warming each room at the optimum time. Another product can learn the amount of time it takes to

achieve a set point and adjust start time accordingly. With this feature (“Adaptive Intelligent Recovery”) turned off, the heating ramp-up does not begin until the set time.

Reporting and Guidance

Most line-voltage connected thermostats report energy use for each zonal heating device. This can help homeowners assess the energy use of each space and make more informed decisions about how to reduce their energy costs. Reporting varies among line-voltage connected thermostat products, such as hourly, daily, weekly, and monthly energy usage reports, hourly energy usage reporting for the previous 24 hours and daily usage for the past month. Energy use for each room per day, along with temperature and humidity may also be available.

Figure 3. Example of Energy Use Reporting per Zone



Courtesy of Sinopé

Data Security

Concerns about data security continue to increase. Some homeowners are understandably concerned that criminals could hack into their wireless, remote-control thermostat system to determine if someone is home. One answer to this issue is a “dual-layer” data encryption system that encrypts the data once, and then encrypts it again so that if the first layer of encryption is broken, the data will still be secure. If the algorithms used are different in each layer, it complies with The Rule of Two, a data security principle from the NSA's Commercial Solutions for Classified Program (CSFC). Other solutions include using Wi-Fi Protected Access version 2 (WPA-2) encryption.

Electric Resistance Heaters⁷

The two primary types of ER heating are central and zonal. Central systems use one electric furnace with ductwork to distribute heat throughout the home. In contrast, zonal heaters heat just one space within a home. They include baseboard, convection heaters without fans, fan-forced heaters, and radiant

⁷ There is some interest in integrating controls for ER zonal heat with controls for more efficient heating systems such as DHPs so the DHP can act as the primary heater with the baseboards as backup. This integration ability is not yet available through thermostats. Because the adoption rate of DHP continues to climb and DHP is now required by Washington State Code for electrically heated homes, the market demand for such an integration package may increase.

heaters—typically floor radiant. Some homes use a ductless heat pump (DHP) for the main living areas and ER zonal heaters for bedrooms and other smaller rooms.

All line-voltage thermostats in this study can control electric baseboard heaters and convection wall heaters without fans. Some, but not all, can also control fan-forced heaters and/or radiant heat. See Table 1 for the capability of specific products.

Baseboard Heaters⁸

Baseboard heaters typically use 250W per foot of length (but can vary from about 175W to 325W per foot) – an 8-foot section would use about 2,000W. A thermostat rated for 4,000W could control four 4-foot baseboard heaters. There is variation among the thermostats – some can handle up to 2,750W at 240V, others can handles up to 3,750W, 4,000W, and 5,000W. To control multiple heaters, wiring would run from the thermostat to the heaters in series and back to the thermostat. With baseboard heaters that have built-in bimetallic thermostats, occupants can turn that thermostat up to full power and control the heater with the line-voltage connected thermostat⁹.

Fan-Forced Heaters

Fan-forced heaters require a deadband control interval longer than that used for baseboard heaters. The 15-second short cycle of most thermostats controlling baseboard heaters can cause premature motor failure in fan motors. A typical thermostat cycle for fan-forced heaters is 5 to 15 minutes, which results in a greater deadband and lower energy savings. A few thermostats (King Electric, Sinopé, and Stelpro) have this capability.

Radiant Floors

Controlling radiant floors requires a ground-fault circuit interrupter (GFCI) to detect shock hazards. This could be especially important for a home having a bathroom with a heated floor. Radiant floor control is the only heating control offered by Nuheat. Sinopé, Stelpro, and King Electric also have radiant floor control capability. All allow control based on air temperature or floor temperature using temperature probes in the floor.

PRODUCT OVERVIEW¹⁰

This section provides a summary overview of the capabilities of the reviewed line-voltage connected thermostats and includes a product comparison table (Table 1). A brief discussion of quality standards is included.

⁸ Some wired Low-Voltage Thermostats are able to control multiple baseboards with a higher combined wattage than a line-voltage connected thermostat, by using linked relays. However this is discouraged by some heater and thermostat manufacturers because a relay in a baseboard heater could add more heat than what the heater is designed for.

⁹ According to CaSA technical support, this is not officially recommended as there may be some downsides to that strategy (Casa 2016). A more dependable option is to bypass the integral thermostat.

¹⁰ Although the research focused on line-voltage thermostats, WSU included a couple of products that are low-voltage thermostats that use relays to control zonal ER heat and have advanced connected and programmable features comparable to the line-voltage thermostats.

Product Analysis

Line-voltage thermostat products from seven manufacturers (CaSA, Empowered Homes, King Electric, Nuheat, Sinopé, Stelpro, and Walker Technologies) are reviewed in this report. All of these products are programmable, connected thermostats able to control ER heat, and are available in the U.S. and Canada. All but one (King Electric) are Canadian. A comparison table is found in this section, and details of the products themselves are in Appendix D.

All seven manufacturers surveyed produce connected models, and four (CaSA, Empowered Homes, Sinopé, and Stelpro) may be considered “smart” because they are able to connect to a home automation system or other devices to sense occupancy or weather conditions and adjust temperature accordingly. Some manufacturers offer different models that use different communication protocols (for example, ZigBee or Z-Wave); three use ZigBee, one uses Z-Wave, four use Wi-Fi, and one uses Bluetooth while one other used a protocol called Neviweb.

Most can produce reports of a home’s daily or monthly energy use, and Mysa will give suggestions on how to save more energy. Geofencing or geolocating appears to be one of the features most desired. The new Mysa by Empowered Homes and Stelpro’s new Maestro thermostat have this capability. Some thermostats are able to reduce the heating set point if they detect that a window or door is open (Stelpro Maestro and King Electric).

All products control ER baseboard heat, except Nuheat, which is designed specifically to control radiant floor heat – their own flooring or others. King Electric, Sinopé, and Stelpro are able to manage radiant floor heating, and five (all except CaSA and Nuheat) can control fan-forced ER heat by adjusting their heating algorithms to long interval cycles to avoid burning out fan motors.

Five of the thermostats are able to control a maximum combined heater load of 3,750W to 4,000W, and one (Walker Technologies) is able to control 5,000W of baseboard usage. Nuheat does not have a maximum baseboard load because it only controls ER radiant floor heat.

Manufacturer prices, in USD, range from \$80 to over \$200 (Nuheat and Walker Technologies). A group of thermostats from four Canadian manufacturers (Sinopé, Stelpro, CaSA, and Empowered Homes) that have the most similar features (connect to home automation, control 3750W to 4000W, sense weather data and occupancy) are all priced at under \$100.

Product Comparison

Table 1. Comparison of Line-voltage thermostat products*

Manufacturer	Sinopé	Stelpro	CaSA	King Electric	Walker	Nuheat (Pentair)	Empowered Homes
MFR origin	Canada (Quebec)	Canada(Quebec)	Canada(Quebec)	USA (Seattle)	Canada (BC)	Canada (BC)	Canada (Newfoundland)
Model	TH112ORF	Ki	Caleo	Atmoz	WZ LVS250	Signature	Mysa
MFR cost in US Dollars (approx. as of January 2018)	\$80	\$95	\$100	\$140	\$239	Over \$200	\$100
# of LVCT products by MFR	4	3	1	2	1	1	1
Communication protocols from thermostats to Internet	ZigBee or Neviweb (RF)	ZigBee or Z-Wave	Wi-Fi	Wi-Fi, Bluetooth	ZigBee	Wi-Fi	Wi-Fi
Data encryption	Dual layer	Depends on home automation system	Dual layer	WPA-2 and Ayla server	No		WPA-2
Public spaces model	Yes	No	No	Yes	Yes	No	No
Max distance from thermostat to web interface	30 feet from web interface or another thermostat	30 feet from web interface or another thermostat	N/A; thermostat uses Wi-Fi directly, no hub interface	N/A; thermostat uses Wi-Fi directly, no hub interface	30 feet from web interface or another thermostat	N/A	N/A
Occupancy sensing	No	No (yes, with new tstat Maestro)	Geolocation	No	built-in, 2 tstats required	Through Nest	Geolocation
Weather data	Outdoor Temp	Outdoor Temp	Relative humidity	No	No	Yes	Weather data
Energy management reports	Hourly for past day, daily for past month	As per automation system	Limited	No	Hours of operation in past 24 hours	hourly, daily, weekly, monthly usage	Yes, plus suggestions for saving energy
Baseboards	Yes	Yes	Yes	Yes	Yes	No	Yes
Fan-forced	Yes (long-cycle)	Yes using ZigBee, Maestro too No using Z-Wave	No	Yes	Yes	No	Yes
Radiant floor	Yes	Yes	No	Yes (model 41E-04BL-WH)	No	yes	No
Smart home integration	Samsung SmartThings, Control-4, RTI	Vera, Wink, Nexia, SmartThings	IFTTT	No	No	With Nest	IFTTT and APIs - Apple HomeKit, Echo, Google Home, Alexa, Wink, SmartThings
Max combined heater load	4,000 W	4,000 W	3,750 W	3,840 W	5,000 W	N/A	3,800 W

* Subject to change – information is from January 2018

Quality Standards

Performance standards for line-voltage electronic thermostats are lacking in both Canada and the U.S. This is expected to change as more advanced line-voltage connected thermostats reach the market. The motivation to develop and adopt standards is likely greater in Canada since the majority of current line-voltage connected thermostat manufacturers are Canadian. Natural Resources Canada is considering amending regulations to include performance standards for line-voltage thermostats within 2 to 3 years (Mortazavi 2017).

At this time, there does not appear to be imminent regulatory movement in the U.S. The National Electrical Manufacturer's Association (NEMA) set standards for thermostats in 2014, "Residential Controls – Electrical Wall-mounted Room Thermostats" (NEMA DC 4-2013), but these do not include performance requirements. ENERGY STAR has specifications for thermostats, but do not yet include line-voltage models, although this has been discussed for several years and may be added in the future (Dunsky 2014).

Underwriters Laboratories (UL) and its Canadian counterpart, the Canadian Standards Association (CSA), use common standards to test products for safety and performance, and have reciprocity. Therefore, as Canada continues to develop its standards, it may give the U.S. market some needed assurance of quality.¹¹ Any future quality standards for the Canadian line-voltage connected thermostat products are likely to influence the U.S. market.

MARKET ASSESSMENT

This market assessment uses regional data to identify the number of single family and multifamily homes that use ER heat in the region. It identifies the number of manufacturers in the market and estimates the upside potential for increased product sales.

ER Heated Homes in the PNW

Zonal ER heat is used in many homes in the Pacific Northwest (PNW) because of low first cost compared to more efficient heating systems. The lack of natural gas availability in rural areas and the relatively low price of electricity in the region also drive their adoption.

The low cost explains why electric baseboards are predominant in lower-income multifamily homes, dorms and motels, and vacation cottages.¹² Over 80% of the region's zonal ER homes are in multifamily buildings (Baylon 2013) and typically have small loads compared to single family homes. In the Eugene Water and Energy Board (EWEB) region, 80% of multifamily housing had low-income residents, according to a study from 2002 (Robison 2002).

¹¹ UL 873 (12th edition) covers U.S. manufacturers and CSA C828-2013 covers Canadian manufacturers for energy efficiency performance requirements such as control intervals (duty cycling) and C22.2 #24-2015 for safety.

¹² Eugene Water and Energy Board's (EWEB) Comfort STAT program replaced all bimetallic thermostats with electronic thermostats (either programmable or not) in customer's homes found that low-income families accounted for 80% of the participants in multifamily homes and about 50% in single-family and duplex homes (Robison 2002).

According to the Residential Building Stock Assessment (RBSA), electric baseboards are used as the primary and secondary heating system in the Northwest in the percentages shown in Table 2. The percentages do not include the use of ER fan-forced heaters or radiant floors, so the percentages are understated.

Table 2. Baseboard Heating as Primary and Secondary Heating Source in Various Housing Types

	Primary	Secondary
Single-Family	12.3%	21.8%
Manufactured	1.5%	8.9%
Multifamily	80.6%	0.8%

Market Sales¹³

Although there is little or no data on the line-voltage connected thermostat market in the Pacific Northwest, all indications are that the current line-voltage thermostat market is dominated by bimetallic thermostats. In April 2016, CLEAResult surveyed manufacturers, retailers, and wholesalers about the local market for line-voltage thermostats. Despite incentives for electronic line-voltage thermostats, the survey found that the vast majority of line-voltage thermostats sold in early 2016 were bimetallic. One wholesaler reported that 95-99% of line-voltage thermostat sales are bimetallic. A manufacturer who produces both bimetallic and electronic line-voltage thermostats reports that 90% sold are bimetallic, and of the electronic thermostats, a higher percentage is sold through retail and not wholesale. Based on this information, it is reasonable to infer that the regional market potential is nearly as large as the number of zones in homes that use ER heat.

Number of Manufacturers

In 2014, a 50-page Canadian market analysis for line-voltage thermostats report was published that had no mention of the word “connected” – the report was published just before the trend toward line-voltage connected thermostats in Canada. Authors used data from two utilities and shipping data from two major retailers, because there was no industry association statistics for market data of thermostat sales in Canada.

Since the Canadian analysis, the market has changed significantly. Today there are at least seven manufacturers of connected, electronic line-voltage thermostats on the market, with thirteen line-voltage connected thermostat products between them. Two of those products are new as of 2018 and have just recently become available. Given the strong trend toward connectivity, the number of available line-voltage connected thermostat products may increase in the near future (Dunsky 2014).

It is uncertain, however, if the market can handle an increase in demand of line-voltage connected thermostats. The manufacturers are mostly small and three of them have estimated total sales to date of 2,000, 6,000 and 8,000 units; two manufacturers are only about three years old; and one has just started shipping their only product in 2018. One manufacturer estimated that U.S. sales are only about 9% of total worldwide sales.

¹³ According to the Energy Information Administration (EIA), 91 million homes use thermostats to control heating, and 25 million of these have a programmable thermostat. There is no indication how many of these are line-voltage thermostats.

Six of the seven reviewed products are from Canadian manufacturers. One possible reason that most line-voltage connected thermostat manufacturers are Canadian is because there is no incentive from Energy Star. Current ENERGY STAR specifications for connected thermostats exclude line-voltage thermostats from consideration (ENERGY STAR-1 2017).

Also, the percentage of single family homes that use electric baseboard heating is significantly greater in Canada than in the PNW. Thirty-six percent of all Canadian homes employ baseboard heaters, and in Quebec Province this value rises to 77% (Natural Resources Canada 2016). In contrast, in the PNW, electric baseboards are used as primary heating systems in only 12.4% of single-family homes – 1.5% of manufactured homes, and 80.6% of homes in multifamily buildings (Baylon 2012, Baylon 2013). The prevalence of electric heat in Canada may also be due to a lack of natural gas availability. Interestingly, residential electric rates in Seattle and Portland are almost double those in Montreal (Hydro Quebec 2016), so paybacks for efficiency improvements could be significantly more attractive in the PNW than in parts of Canada.

ENERGY SAVINGS

In order to estimate the technical regional potential for replacing bimetallic line-voltage thermostats with connected line-voltage thermostats (line-voltage connected thermostats), studies with energy savings findings are necessary. However, no such studies were found. There are studies on connected low-voltage thermostats that may suggest the types of savings available with line-voltage connected thermostats, as many of the connected features are the same in both types of thermostats.

A few studies on line-voltage thermostats were found that research energy savings of electronic vs bimetallic thermostats, and programmable vs non-programmable thermostats¹⁴. However, programmable is not the same thing as connected. There is a gap in research of energy efficiency and energy savings of line-voltage connected thermostats.

Electric Line Voltage Thermostat Efficiencies

A number of field studies compared energy savings when removing bimetallic line-voltage thermostats and replacing them with electronic thermostats. These savings varied from about 5% to over 9%. Most of these studies are old, and some are inconclusive (Seattle City Light 2006).

As of April 2016, the RTF estimate of potential savings for replacing a bimetallic line-voltage thermostat with an electronic model was 5%. These are fairly small savings, leading RTF to note the importance of future research to study the variability of actual energy savings (Hadley 2016).

EWEB's 2002 study identified energy savings for electronic programmable thermostat replacements at approximately 9.4%. Both programmable and non-programmable electronic line-voltage thermostats were used as retrofits (Robison 2002)

¹⁴ University of Quebec at Trois-Rivieres and Hydro Quebec performed studies on programmable line-voltage thermostats, estimating savings of 4% and 3.6% respectively. The studies are not significant for connected thermostats. However, more information on these studies may be found in Appendix B.

A Northeast Utilities study in 2000 determined the energy usage impact and occupant satisfaction of the replacements of bimetallic thermostats with electronic thermostats (not programmable or connected). It was estimated that heating energy use was reduced by roughly 7.1%, roughly the equivalent of a 1°F decrease in temperature set point (Johnson 2000).

Connected Low Voltage Thermostat Efficiencies

Because of the lack of sufficient data, energy saving results from research on connected low-voltage thermostats is used in this report to estimate regional technical potential. This is reasonable because connected thermostats are programmable. A conservative RTF estimate of 8% is used. BPA, Energy Trust of Oregon, and Puget Sound Energy studies estimate 6% savings with electric forced-air furnaces, and 14% with air-source heat pumps from programmable features. While these savings are for central heating system of different types and for various climates, this demonstrates that the energy savings for this upgrade is significant but highly variable. The base case for the replaced thermostats is that they are not connected – they can be bimetallic, electronic, or programmable, but not connected. A conservative estimate of 8% is used for the base case.

Table 3. Estimated Energy Savings Results per Research Study*

	Year	Line-voltage: Bimetallic to Electronic	Low-Voltage: Not Connected to Connected	Estimate used for report's Regional Technical Potential
RTF**	2016	5%		5%
EWEB	2002	9.4%		
Northeast Utilities	2000	7.1%		
RTF**	2017		6-14%	8%
Total savings				13%

* Total savings of 13% for bimetallic to connected is very rough because no research has been found for this type of replacement.

** RTF did not perform original research. Estimates are compiled from other studies.

Inferring Energy Savings for Connected Line-Voltage Thermostats¹⁵

There are no studies that assess the energy saved by replacing a bimetallic line-voltage thermostat with an electronic programmable line-voltage thermostat, much less a connected line-voltage thermostat. In order to estimate regional technical potential, it was necessary to infer savings from multiple studies.

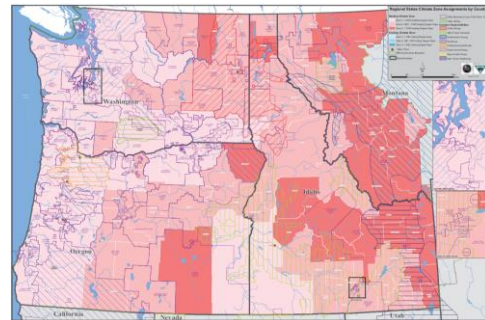
An estimate of 13% energy savings to replace bimetallic line-voltage thermostats with line-voltage connected thermostats comes from the two RTF measures. The RTF uses an estimate of 5% energy savings for replacement of a bimetallic line-voltage thermostat with an electronic model, and an estimate of 6% to 14% savings for a connected low-voltage thermostat. Using 8% for the connected thermostats, as discussed in the previous section, plus 5%. This should be taken as a reasonable placeholder estimate pending the completion of studies by Puget Sound Energy that will hopefully provide updated savings estimates for replacing bimetallic thermostats with line-voltage connected thermostats.

¹⁵ The estimate of 13% is used later in this report to calculate the regional technical potential.

Regional Technical Potential

The Regional Technical Forum (RTF) estimates the electricity used to heat homes where the primary heating system is zonal electric heat (Table 4) (NWPCC 2016), (Hadley 2017). Estimates are broken out for the three heating zones in the territory. Heating zone 1 is closer to the coast (see lightest color in Figure 5 map), zone 3 in the inland mountainous areas has the greatest amount of heating need (darkest red in Figure 5), and zone 2 is in between.

Figure 4. RTF Heating Zone Map



Assumptions for energy use values were further reduced to compensate for homes that use some wood heat (Hadley 2017). The weighted average annual energy use of the average PNW home is closer to that of a home in zone 1 because that is where 80% of the population resides.

Using data from the RTF and RBSA, the estimated weighted average of annual single family energy use in homes with primary ER heat to be 8,900 kWh/yr. For multi-family homes, the value is estimated at 3,800 kWh/yr. For calculation of regional technical potential (RTP), only single-family and multifamily homes using baseboards as their primary heating system (red type in Table 3) are included, making RTP values even more conservative (Baylon 2012) (Baylon 2013).

Table 4. Annual Heating Energy Use (kWh/year) for ER Homes Estimated with SEEM in the BPA region.¹⁶

Housing Type	Heating Zone			Total	Total **
	1	2	3		
Single family ER annual heating	8,391	10,590	11,739		
Multifamily ER annual heating (fmp)	2,635	4,012	4,968		
Multifamily adjusted*	3,426	5,216	6,458		
Zone distribution of population	80%	15%	5%		
Single family weighted average	6,713	1,589	587	8,889	8,900
Multifamily weighted average	2,740	782	323	3,845	3,800

* Increased by 30% to compensate for data assumption of full insulation

** Rounded to reflect the lack of uncertainty in input data

According to the NWPCC, as of 2015 there were over 4.2 million single-family homes and 1.1 million multifamily units in the PNW (Jayaweera 2017). The RBSA estimates 12.3% of single-family homes and 80.6% of multifamily homes use ER heat as their primary heating source (Baylon 2012) (Baylon 2012). Omitting the use of ER heaters in manufactured homes and as a secondary heating source makes these figures conservative estimates. Accordingly, the number of homes with bimetallic thermostats in the region is roughly:

¹⁶ Energy use of ER heating in manufactured homes and small commercial buildings are not included.

- Single-family homes: 4,203,528 * 12.3% = 517,034 ER-heated homes
- Multifamily units: 1,137,423 * 80.6% = 916,763 ER-heated units

As calculated, the annual weighted average heating energy used by single-family and multifamily homes is roughly 8,900 kWh and 3,800 kWh, respectively. A conservative estimate of energy savings from replacement of a bimetallic thermostat with a line-voltage connected thermostat model is 13%. As indicated in Table 5, the regional technical potential (RTP) would be 120 aMW for both home types.

Table 5. Regional Technical Potential (RTP)*

Home Type	# homes in region	% that use ER Heat	# ER Homes	Weighted Average ER Heat Energy (kWh/year)	Energy Savings***	RTP (MWh/year)	RTP (aMW)**
Single-family	4,203,528	12.3%	517,034	8,900	13%	598,210	68.3
Multifamily	1,137,423	80.6%	916,763	3,800	13%	452,880	51.7

* MWh/year = ((# of Homes in region)(% that are ER heated)(weighted average annual kWh/yr)(energy savings)(.001)

** Average MegaWatt/year = aMW/year = (MWh/year) ÷ 8760 hrs/yr

*** RTF savings estimate of 5% bimetallic to electronic, plus Energy Star estimate of 9% simple to programmable, less 1% fudge factor

Cost Effectiveness

Number of Thermostats per Home

The estimate of the number of thermostats per home varies from 3 to 9. A study by Hydro Quebec estimates an average of 9.5 zonal thermostats per home (Michaud 2009) and the EWEB study replaced five thermostats per home (Robison 2002). BPA assumes three to five thermostats per home (BPA 2017-1, 109). The RTF estimates six thermostats per single-family home and four per multifamily home (NWPCC 2016). The cost effectiveness calculations in this paper use the RTF's estimates.

Cost

Four of the thermostats mentioned in this paper cost \$100 or less, however some of them need an interface to work, at added cost. Costs of King Electric, Walker Technologies, and Nuheat, range from \$150 up to \$350.

Benefit Cost Ratio

The Northwest Seventh Power Plan estimates the benefit cost ratios for electronic thermostats (not connected) as seen in Table 6 (NWPCC 2016, presentation tab). The multifamily benefit cost ratio for heating zone 1 is under 1.0. Research findings on energy savings for line-voltage connected thermostats (for which there are currently no studies) could potentially bring this ratio up.

Table 6. Benefit Cost Ratio of Electronic Line-Voltage Thermostats

Housing Type	Heating Zone 1	Heating Zone 2	Heating Zone 3
Single-family	1.3	1.7	1.8
Multifamily	0.8	1.2	1.5

Benefit/Cost Ratio

A benefit cost ratio is the ratio of the present value of the total benefit of a measure, including energy savings and utility non-energy benefits, to the present value of the total cost of implementing the measure, including both utility and customer costs, as calculated over the lifetime of the measure. Benefit cost ratios above 1.0 indicate that a measure is beneficial to a utility and its ratepayers on a total resource basis, equivalent to a discounted payback equal to the life of the measure. However estimating utility non-energy benefits is complex and utilities may have reason to require benefit cost ratios greater than 1.0 or implement some measures with benefit cost ratios less than 1.0.

Source: NWPCC

Simple Payback

The average cost for the four most affordable line-voltage connected thermostats is approximately \$100. As noted previously, a typical single-family home with zonal electric heating is assumed to have six thermostats, while a multifamily unit may have four.

The cost per home is as follows:

- Single-family homes: \$100/ thermostat * 6 thermostats = \$600
- Multifamily units: \$100/ thermostat * 4 thermostats = \$400

The annual energy cost savings per home is as follows:

- Single-family homes: 8,900 kWh/year * 13% savings * \$0.10/kWh = \$116/year
- Multifamily units: 3,800 kWh/year * 13% savings * \$0.10/kWh = \$49/year

The simple payback would then be:

- Single-family homes: \$600 / \$116 = 5.2 years
- Multifamily units: \$400 / \$49 = 8.2 years

MEASURE DEVELOPMENT

Product Readiness

BPA scores technologies to determine their readiness for the market and identify any research or program gaps. The three readiness categories are market/commercial readiness, technology or product readiness, program readiness. A complete description of the readiness criteria is in Appendix E.

Table 7: BPA Technology Readiness Criteria and Scores for line-voltage connected thermostats

BPA Technology Readiness Criteria		Explanation
Market/Commercial Readiness <i>How available is the technology in the market?</i>	Level 4 (or 3)	Line-voltage connected thermostats are commercially available in the NW from at least two manufacturers. There is limited market research, yet growing market interest.
Product Performance <i>Are the energy savings viable?</i>	Level 2 (or 1)	The concept has been validated through the performance of other similar thermostats, and by manufacturers.
Program Readiness <i>How ready is the technology for a program, in terms of cost effectiveness, program delivery, and risk assessment?</i>	Level 2	There appears to be preliminary analysis showing a pathway to cost effectiveness.

Barriers

Although Northwest utilities have been offering incentives for electronic line-voltage thermostats for nearly two decades, there has been little uptake, in part due to cost and split-incentives. CLEAResult reported “this is a very price-sensitive demographic and even the price bump to a basic digital thermostat is a hard sell. Wireless digital thermostats are not moving in the market at all and would be a very hard sell indeed.” (Bramen 2016). CLEAResult estimated that the average difference between the retail price (before incentives) of bimetallic and electronic thermostats is about \$35, or a 70% premium for electronic thermostats (Bramen 2016).

Many multifamily housing building managers and owners that would purchase thermostats do not receive return on investment from energy savings benefits. These benefits accrue to the tenants who are likely to pay the utility bills. This creates a split-incentive, where owners do not see an investment in an energy efficiency measure such as line-voltage connected thermostats as recoverable. The return on investment is further diminished because a building owner would need to purchase a separate thermostat for each heating zone in the unit.

The CLEAResult survey also revealed that retailers and wholesalers are not aware of the types of consumers who purchase electronic line-voltage thermostats, and some sellers do not promote them (Bramen 2016). It appears unlikely that an increase in sales can occur without some sort of stimulus such as targeted incentives and education.

Customer uptake

Online product reviews of the line-voltage connected thermostat products in this report find that customers give them high ratings and are not experiencing major challenges when installing or using them. A number of thermostats offer pre-set programming options for those users who do not want to, or are unable to, program the thermostats themselves. Programming features favored by users include multiple custom-programmable periods per day, replicating configuration and schedule settings to other thermostats, reverting to 55 °F minimum space temperature if the thermostat loses communications or the thermostat is defective, multifamily units that adjust temperature based on lack of occupancy or if doors or windows are open.

In addition to programming advances, other improvements that increase usability include easier programming, better screen interfaces, pre-programmed options, program recovery after power outages, programming remotely from a smart phone or computer, modification of programming through machine learning (due to occupancy, weather, etc.).

There are some studies that show the reluctance of users to use the programming capabilities of programmable thermostats. According to the Residential Building Stock Assessment (RBSA), 69% of homeowners self-reported using programmable heating set points as a regular part of their use pattern during the heating season (Baylon 2012) (Baylon 2013). ENERGY STAR reports that as many as 30% of homeowners may be unable, unwilling, or uninterested in using default programs or customizing their thermostat's program. This could be due to a belief that setting back their thermostat does not actually save energy. As many as 50% of homeowners manually adjust their thermostat's setpoint. This reluctance to program thermostats and reliance on the thermostat's default program reduces energy savings (ENERGY STAR-3 2017).

Non Energy Benefits

Significant non-energy benefits may help to accelerate adoption of line-voltage connected thermostats, especially those with advanced smart features. Homeowners may appreciate increased comfort (for example a warm house when they get out of bed), pre-set programmability, remote control through smart phones and other devices, and connection to home automation systems. Multifamily property owners may welcome lower operation and maintenance costs, ability to monitor and control heating systems, receiving alerts for freezing pipes or high humidity, and happier tenants. Additionally, utilities may benefit from demand reduction, project savings validation, and smart grid connectivity.

Demand Response

In addition to energy efficiency savings, line-voltage connected thermostats can provide opportunities for demand response (DR). Natural Resources Canada estimates that almost two-thirds of residential peak demand comes from space heating (Natural Resources Canada 2016). To enable DR, customers need to give their local utility or utility program third-party implementer permission to override their thermostat programming. During peak demand events, this can be achieved by modulating temperature set points, simple step-down of temperature set points, and ramping up space temperature prior to the event.

Some of the thermostats described in this paper can make use of proportional control and power electronics to provide multiple switches per minute, resulting in almost continuous modulation of heating output. Fluctuations in space temperatures are generally less than 0.9°F and, unlike forced-air systems, most occupants will not notice changes in space temperature or changes in blower sound or airflow. Set point ramps have been found to be more effective than step changes in set point in achieving demand response (Fournier 2016-1).

According to a 2016 study by the Institute of Research of Hydro Quebec (IREQ-LTE), ramping up the space temperature set point by 1.8°F two hours prior to a peak demand event, ramping it down to 1.8°F below the starting temperature when the event starts, and then returning it to the starting set point after the event results in up to a 61% reduction in heating demand during the event (Fournier 2016-1).

BC Hydro is currently studying the impact of smart controls for electric baseboard heating on demand response. The intended outcomes of the study, “Load Management – Thermostats (Baseboard)”, include: understanding demand impacts achieved through various load control strategies applied to baseboard heating systems in single family homes; testing the impacts to home occupants and acceptance of load control strategies, and; understanding how emerging connected home products may impact electricity usage (Intihar 2016).

Current Measures

Current BPA Measures

The development in advanced thermostats for zonal ER heat may help towards filling a gap in the current list of BPA measures. BPA seeks to find a low cost solution for connected thermostats for zonal ER heat for single family, multifamily, and manufactured housing applications.

There is one current BPA residential thermostat measure specifically for line-voltage thermostats, as stated in section 10.8.1 of the 2017-2019 BPA Implementation Manual. An \$18/unit incentive is offered for replacing each bimetallic line-voltage thermostat with an electronic line-voltage thermostat in existing single-family homes and existing multifamily low-rise and mid-/high-rise units. Programmable electronic line-voltage thermostats are allowed if their temperature and program settings are maintained during power failures (BPA 2017-1). BPA publishes a qualified products list for these programmable thermostats (BPA2018).

BPA Current Residential Electronic Line Voltage Thermostat Measure

Replace line-voltage, bi-metal thermostats with:

- Existing SF, existing MF low-rise and mid-/high-rise
- Digital display
- Electronically line-voltage type
- Thermistor temperature sensing element accurate to within 1.5 degrees
- UL- or CSA-listed for use with application
- If programmable, must maintain temperature and program settings during power failures
- \$18/unit

There is a residential incentive for Smart Thermostats. However, the base case and replacement is for homes with existing forced-air furnaces, or air and ground-source heat pumps. The thermostats intended for this measure are low-voltage, not line-voltage.

RTF also advised BPA to pursue a separate measure. Therefore, this research focused on communicating thermostats for zonal electric resistance heating and does not duplicate any measures in the current portfolio.

Northwest Incentives

Puget Sound Energy Incentives

Puget Sound Energy offers \$50 per thermostat for replacing bimetallic thermostats in multi-family buildings with in-unit models.

RTF Measures

The Regional Technical Forum approved a planning measure for residential electronic line-voltage thermostats in April 2016. A planning measure indicates that there is enough data to estimate savings, in this case 5% per unit, but more research is needed for the measure to be proven. The measure is for replacing bimetallic line-voltage thermostats.

Canadian Utility Incentives

Major Canadian utilities began offering incentives for programmable thermostats that control electric baseboard heaters about 20 years ago, but most of these incentives have since been terminated due to satisfactory adoption rates of the technology across most housing sectors. Incentives for pilot projects are still available (Fournier 2016, personal). NB Power still offers a \$25 rebate for line-voltage connected thermostats controlling electric baseboard heaters (NB Power 2016).

Research

The current rise of connected line-voltage thermostats and lack of studies showing energy savings when they replace bi-metallic or simple electronic thermostats, point to a gap in research. The current RTF research recommendation is for electronic line voltage thermostats which do not specifically include connected features and therefore may not be applicable to future line-voltage connected thermostat research projects.

In April 2016 the RTF published a proposed research strategy to support energy savings estimates for electronic line-voltage thermostats for single family and multi-family homes. Current RTF estimates for potential savings for replacing a bimetallic thermostat with an electronic model in homes with zonal electric heat without a ductless heat pump is 5%.¹⁷ The RTF's research objective is to estimate the average savings due to a whole-building retrofit, as well as capture the number of thermostats replaced in each building (Hadley 2016). To date, no PNW utilities have expressed a willingness to pursue this research (Anziano 2016). Researchers studying savings from connected line-voltage thermostats may

¹⁷ Applications with DHP are not expected to be cost-effective.

find details of the RTF's research strategy informative, even though it is specifically for electronic and not connected line-voltage thermostats.

Puget Sound Energy

Puget Sound Energy, in partnership with the WSU Energy Program, was the recipient of a Community Energy Efficiency Grant (CEEP) grant to administer an electronic line voltage thermostat (ELVT) pilot program. The objectives of the pilot are to increase access to emerging technologies in multifamily rental units and quantify the energy savings from upgrading existing bi-metal thermostats controlling line-voltage electric resistance heat. Each heating zone of the home will receive a directly installed connected thermostat by a licensed electrician. Installations include a low-voltage Honeywell EConnect™ Wireless Thermostat, RedLINK™ Internet Gateway, and wireless equipment interface module ("EIM"). Property managers must agree to maintain the equipment and facilitate transferring access to new residents upon turnover. Residents are provided with educational materials highlighting the benefits and functionality of the thermostats including the ability to control set-points via an online portal or mobile app. Preliminary results are anticipated in 2018 after a full heating season. Sinopé thermostats have been added as a Phase 2 of the project, with results not available until 2019 (Stewart 2017).

A potential Phase 3, using newly developed Mysa thermostats with geolocating features, is being explored with BPA. These thermostats are line-voltage connected thermostats. Results for this phase, if realized, would potentially be available late 2019.

CONCLUSIONS

As documented in this report, line-voltage connected thermostats can provide:

- Up to 13% energy savings
- Regional technical potential of 120 aMW (1,051,000 MWh/year)
- Simple payback of about five years for single-family homes and seven years for multifamily homes
- Peak demand reduction up to 61%
- Improved customer comfort and convenience
- Opportunities for increased income and property protection for multifamily building owner

Connected line-voltage thermostats with features similar to advanced low-voltage thermostats are relatively new in the market. Line-voltage connected thermostats currently have a very small penetration rate for controlling ER heaters in the PNW (Hadley 2016). A number of promising line-voltage connected thermostat models are now available for roughly \$100, an attractive price point with a 5-year simple payback for single-family homes. Therefore, there seems to be a great opportunity for PNW utilities to offer a more cost effective alternative for price sensitive markets.

Increased availability of features that deliver comfort and convenience will likely drive demand for line-voltage connected thermostats for ER heat applications. Wireless communications have become ubiquitous in the region with smart phones, and home automation systems are gaining a foothold in the market, offering additional opportunities for remote monitoring and control as well as system integration. Utilities can use remote control to implement demand reduction programs through line-voltage connected thermostats.

There is some interest in integrating controls for ER zonal heat with controls for more efficient heating systems such as DHPs where the DHP would act as the primary heater with the baseboards as backup. This integration is not yet available. Although the adoption rate of DHP continues to climb and Washington State Code now requires DHPs for electrically heated homes, the need for such an integration package may be increasing.

As shown in this report, most of the research for electronic thermostats comes from studies completed in the late '90s and early 2000s. In order to support incentives for utility programs more research to validate energy savings and cost effectiveness needs to be done. A new study could determine reasonable estimates of energy savings for different climates within the region, building types, occupancies, and thermostat choices, as well as integration with home electronics and automation systems. It could also explore strategies for overcoming beliefs among building owners a split incentives and trade allies that programmable thermostats are not useful or cost-effective.

If the study results are promising, BPA may want to consider revising their measure for baseboard thermostat replacement that currently only calls for – and only takes credit for energy savings from – simple electronic models. The region (NEEA) could work with line-voltage connected thermostat manufacturers to make their products more readily available. In the future, utilities may capitalize on opportunities for demand reduction.

RECOMMENDATIONS

The following recommendations may be considered in order to increase adoption of line-voltage connected thermostats.

Perform Field Studies and/or Modeling

Reliable third-party data on energy savings from replacing bimetallic thermostats with line-voltage connected thermostats is scarce. Field testing to determine energy savings for this measure is lacking. Studies that have been done are small, outdated, and/or not in the PNW, or used thermostats with older technologies (RTF 2016).

Funding robust field testing in the region using the latest line-voltage connected thermostats now available may include an investigation of the impacts of integration with home automation systems. Collaboration with RETAC and other utility organizations and building from the RTF research plan is suggested.¹⁸ The most immediate opportunity may be to collaborate with Puget Sound Energy, which recently started a study that may deliver useful data (Stewart 2017). While the thermostats installed in the first phase of that study are low-voltage models using relays; the study subsequently installed line-voltage connected thermostats in Phase 2, and the third phase will involve another line-voltage connected thermostat model. BPA has expressed interest in collaborating with PSE on this research.

Upgrade BPA Measure for Electronic Thermostats

The current BPA measure for baseboard control simply requires electronic thermostats. Although programmable thermostats are allowed, the energy savings are assumed to come just from a reduction in deadband size. This seems to leave the majority of potential savings available from using line-voltage connected thermostats (programmability, remote control, occupancy sensing) unrealized. If studies demonstrate savings then BPA may want to consider updating or adding an additional measure.

Promote Non-Energy Benefits

Many consumers value non-energy benefits as much as, if not more than, energy savings. These can include comfort and convenience, reduced operation and maintenance costs, and increased income for multifamily building owners (see Non-Energy Savings above for a full listing of these benefits). These features should be clearly communicated to target audiences.

More occupant education and assistance may be needed for proper programming and use, and building manager engagement may be needed to ensure adequate utilization of the technology to deliver persistent energy savings. The issue of split incentives in this sector may be a disincentive for investments by owners, particularly if they are out of state, but the non-energy benefits for owners listed above under Non-Energy Benefits may help mitigate this (Heller 2016).

Utilities may also benefit from this measure beyond reduction of energy use and demand reduction, such as from feedback on actual savings from efficiency measures, which may help the utilities more actively promote this measure.

¹⁸ The RTF's strategy suggests including multifamily homes and avoiding homes with DHP, which are seen as not cost-effective (Hadley 2016).

Engage Manufacturers

If the field testing yields promising results, consider engaging the manufacturers of line-voltage connected thermostats to make them more available in the PNW. It is likely that these manufacturers would be interested in expanding their markets to the region, especially since energy is more expensive than in Canada, where most line-voltage connected thermostat manufacturers are located, and a utility incentive – no longer readily available in Canada – makes paybacks more attractive. Upstream incentives for manufacturers or distributors could be explored.

Support National Recognition of Line-Voltage Connected Thermostats

National recognition can be a market driver for broader adoption of line-voltage connected thermostats. Line-voltage connected thermostats are not yet included in ENERGY STAR specifications and certification, partly due to EPA's focus on control of centralized rather than zonal HVAC systems. However, it may be productive to encourage the ENERGY STAR Connected Thermostat Metrics Stakeholders group to consider adding s to their specifications, or at least stay abreast of the group's activities. This group includes representatives from most of the major manufacturers of low-voltage thermostats. Energy savings methodologies and the development of energy rating indices from additional field studies may also lead to consideration in the ASHRAE 90.2 committee and a HERS (Home Energy Rating System). This may support utilities' whole-building incentive programs.

Appendix A. References

- Amer, Waseem. "Personal communication between Michael Lubliner, WSU Energy Program, and Waseem Amer, CEO of Cielo WiGle, Inc." January 2107.
- Anziano, Jennifer. "Private conversation between Rob Penney, WSU Energy Program, and Jennifer Anziano at the RTF." December 14, 2016.
- Bauman, Mike. "Personal communication between Rob Penney, WSU Energy Program, and Mike Bauman, Product Marketing Specialist, Honeywell." May 2017.
- Baylon, David et al. "2011 Residential Building Stock Assessment: Single-Family Characteristics and Energy Use, by Ecotope." *NEEA.org*. September 18, 2012.
<http://neea.org/docs/reports/residential-building-stock-assessment-single-family-characteristics-and-energy-use.pdf?sfvrsn=8>.
- . "Residential Building Stock Assessment: Multifamily Characteristics and Energy Use." *NEEA.org*. September 5, 2013. <http://neea.org/docs/default-source/reports/residential-building-stock-assessment--multi-family-characteristics-and-energy-use.pdf?sfvrsn=4>.
- BPA. "2016-2017 Implementation Manual." *BPA*. 2017.
https://www.bpa.gov/EE/Policy/IManual/Documents/IM_2017_10-11-17.pdf.
- . "2017-2019 Implementation Manual." 2017-1.
https://www.bpa.gov/EE/Policy/IManual/Documents/IM_2017_10-11-17.pdf.
- . "Programmable Line Voltage Thermostat Qualified Products List." January 25, 2018.
https://www.bpa.gov/EE/Sectors/Residential/Documents/BPA_Line_Voltage_Thermostat_QPL.pdf.
- Bramen, Matt. "A Survey of Local Markets for Line Voltage Thermostats." April 7, 2016.
<https://nwcouncil.app.box.com/s/ptzafntrg9ab9211z3igz3g2dt857qu3>.
- Burke, Tim. "Balancing comfort and technology with residential thermostats." *Refrigeration Service Engineers Society*. May 2017.
<http://www.rses.org/rsesjournal/balancingcomfortandtechnologywithresidentialthermostats.aspx?idevd=2E2972DE965411DEB2E15C9E55D89593&idevm=eec5cb32203c49a882905bfb88b2e971&idevmid=348436>.
- Cadet. "UPDATED: How to use a smart thermostat with electric baseboards or wall heaters." *Blog post about using relays and thermostats to control line voltage electric resistance heaters*. January 15, 2016. <http://cadetheat.com/blog/wi-fi-thermostat-cadet-heater/>.

Canadian Broadcasting Commission. "Ban Electric Baseboard Heaters: Commission." *CBC News*. April 20, 2011. <http://www.cbc.ca/news/canada/new-brunswick/ban-electric-baseboard-heaters-commission-1.994909>.

Canadian Standards Association. "Performance Requirements for Thermostats Used with Individual Room Electric Space Heating Devices, CAN/CSA C828-13." *walkersys.com*. 2013. <http://www.walkersys.com/wiredproducts/PDFs/C828-06.pdf>.

Casa. "Wi-Fi Thermostat for Electric Baseboards." December 2016. <https://casaconnect.com/en/caleo/>.

Cheema, Jovan. "Personal conversation between Rob Penney, WSU Energy Program, and Jovan Cheema, CSA Group Project Manager - Energy Efficiency & Renewables." May 2017.

Daken, Abigail. "Open letter soliciting contributions of modeling using the CT Metrics software to support the development of a software tool that estimates energy savings from connected thermostat products." *U.S. EPA*. <https://www.energystar.gov/sites/default/files/Connect%20Thermostat%20Datacall%203.pdf> , September 19, 2016.

Desautels, Xavier. "Personal communication between Rob Penney, WSU Energy Program, and Xavier Desautels CaSaConnect." *CaSa*. December 14, 2016. (accessed December 14, 2016).

Dimplex. *Dimplex Connex Wi-Fi Multi-zone Programmable Controller*. May 2017. http://www.dimplex.com/en/electric_heating/thermostats_controls/products/cxwifia/wifi_multizone_programmable_connexm_controller.

Dunsky. *Update of Market Analysis for Line-voltage Thermostats: Final Report*. Natural Resources Canada's Office of Energy Efficiency, 2014.

Ecobee. "Ecobee3 Review: The Best Smart Thermostat for Complete Control." 2016. <https://thesmartcave.com/ecobee3-thermostat-review/>.

Ecotope. "Residential Building Stock Assessment: Metering Study." *NEEA.org*. April 28, 2014. <http://neea.org/docs/default-source/reports/residential-building-stock-assessment--metering-study.pdf?sfvrsn=6>.

Ekhart, Tom. "Personal conversation between Rob Penney, WSU Energy Program, and Tom Ekhard, CEO." 2016.

Empowered Homes. *mysa*. May 2017. <https://getmysa.com>.

ENERGY STAR. "ENERGY STAR® Connected Thermostat Products Discussion Document – Description of Candidate Savings Methodology & Algorithms Implemented in Software. ." September 2016, 2016. https://www.energystar.gov/sites/default/files/DiscussionDoc-ES%20Candidate%20CT%20Field%20Savings%20methods%20implemented%20in%20software_20160915.pdf.

- ENERGY STAR-1. "ENERGY STAR® Program Requirements for Connected Thermostat Products: Partner Commitments." January 2017.
https://www.energystar.gov/sites/default/files/ENERGY%20STAR%20Program%20Requirements%20for%20Connected%20Thermostats%20Version%201.0_0.pdf.
- ENERGY STAR-2. "Programmable Thermostats." June 2017.
https://www.energystar.gov/products/heating_cooling/programmable_thermostats.
- ENERGY STAR-3. "Summary of Research Findings from the Programmable Thermostat Market." June 2017.
https://www.energystar.gov/ia/partners/prod_development/revisions/downloads/thermostats/Summary.pdf.
- Fournier, Michaël. "Email communication between Philip Kelsven, BPA, and Michaël Fournier, IREQ-LTE." September 27, 2016.
- . "Winter Demand Response Using Baseboard Heaters: Achieving Substantial Demand Reduction Without Sacrificing Comfort, by Fournier, Michaël, and Marie-Andrée Leduc." *ACEEE.org*. 2016-1. http://aceee.org/files/proceedings/2016/data/papers/1_88.pdf.
- Gorthala, R, Stoltz, S., and Hagen, E. "Testing and Evaluation of Line-voltage Thermostats, Final Report." 1993.
- Green, Zachary. "Personal communication between Rob Penney, WSU Energy Program, and Zachary Green, COO and Co-founder." *Empowered Homes*. May 2017.
- Guzmán, Christine. "Modeling of Residential Centralized and Baseboard Space Heating Systems." *IEEE 25th International Symposium on Industrial Electronics*.
<http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=7744979>, 2016.
- Hadley, Adam. "Personal conversation between Rob Penney, WSU Energy Program, and Adam Hadley, RTF." June 2017.
- . "Research Strategy (Proposed): Electronic Thermostats for Homes with Zonal Electric Heat." April 19, 2016. <https://nwcouncil.app.box.com/s/e4c8u7bm3cdj2d4lgvmiycxh4ndjkaf>.
- Heller, Jonathan. "Personal conversation between Rob Penney, WSU Energy Program, and Jonathan Heller, President, Ecotope." December 2016.
- Hervieux, Jean-Philippe. "Personal communication between Rob Penney, WSU Energy Program, and Jean-Philippe Hervieux, Customer Service and Technical Support Coordinator ." *Ouellet*. May 2017.
- Honeywell. *EConnect™ Wireless Comfort Control System*. December 2016.
<https://forwardthinking.honeywell.com/products/thermostats/econnect>.

- . *Ecosystem & API Integrators*. May 2017.
<https://forwardthinking.honeywell.com/ecosystemintegrators> .
- Hydro Quebec. "Comparison of Electricity Prices in Major North American Cities, Rates effective April 1, 2016." April 1, 2016.
https://issuu.com/hydroquebec/docs/comp_2016_en?e=1151578/39216309.
- . "Electronic Thermostats." August 2017. <http://www.hydroquebec.com/residential/energy-wise/heating-air-conditioning/electronic-thermostats.html>. .
- Impala, Ed. "Personal communication between Rob Penney, WSU Energy Program, and Ed Impala, Honeywell." December 2016.
- Intihar, Christy. "Phone conversation between Rob Penney, WSU Energy Program, and Christy Intihar, BC Hydro." *and email exchange in April 2017*. October 6, 2016.
- Jayaweera, Tina. "Personal conversation between Rob Penney, WSU Energy Program, and Tina Jayaweera at the RTF." June 2017.
- Johnson, Russ, Dinesh Bhagani, and Steven Carlson. "'Measured Impact of Mechanical Thermostat Replacement,'" Prepared for Northeast Utilities." *ACEEE Proceedings*. 2000.
http://aceee.org/files/proceedings/2000/data/papers/SS00_Panel1_Paper12.pdf.
- Kelsven, Philip. "Email to Michaël Fournier, IREQ-LTE, from Philip Kelsven, BPA." September 28, 2016.
- King. *Line-Voltage Thermostats*. June 2017. <http://www.king-electric.com/product-line-voltage-thermostats.php>.
- Lambert, Les. "Electronic Line Voltage Thermostats: A Worthwhile Retrofit for Baseboard Heat?" *ACEEE 1996 Summer Study*.
http://aceee.org/files/proceedings/1996/data/papers/SS96_Panel1_Paper16.pdf, 1996.
- Michaud, Normand et al. "'Billing Analysis & Environment that "Re-Sets" Savings for Programmable Thermostats in New Homes" prepared for Hydro Quebec." *Energy Program Evaluation Conference Proceedings*. Portland:
http://www.anevaluation.com/pubs/090604_econoler_iepec_paper-lm.pdf, 2009.
- Morin, Monia. "Personal communication between Rob Penney, WSU Energy Program, and Monia Morin, Tech Support, Stelpro." May 2017.
- Mortazavi, Renata. "Personal conversation between Rob Penney, WSU Energy Program, and Renata Mortazavi, Senior Standards Engineer at Natural Resources Canada's Office of Energy Efficiency." May 2017.
- Natural Resources Canada. "Energy Efficiency Trends in Canada 1990 to 2013." *Office of Energy Efficiency*. 2016. <https://www.nrcan.gc.ca/energy/publications/19030>.

- Navigant Consulting. "2011 EM&V Report for the Puget Sound Energy Residential Demand Response Pilot Program - Final Report." *PSE.com*. February 6, 2012.
<https://pse.com/inyourcommunity/Documents/BainbridgeIslandDemandResponseProject.pdf> .
- NB Power. "Smart Habits Rebates are Back!" September 30, 2016.
<https://www.nbpower.com/blog/en/posts/2016/september/smart-habits-rebates-are-back/> .
- Nuheat. *SIGNATURE Programmable WiFi Floor Heating Thermostat*. April 2017.
http://www.nuheat.com/docs/default-source/2017-products-files/signature-thermostat/signature_thermostat_sell_sheet.pdf .
- NWPCC. "Summary of Measure Assessment Methodology and Data Sources for Electronic Line Voltage Thermostats, Version 3.1." *rtf.nwcouncil.org*. November 17, 2016.
<https://rtf.nwcouncil.org/measure/electronic-thermostats> .
- Pardasani, Ajit et al. "Intelligent Management of Baseboard Heaters to Level Peak Demand." *IEEE Electrical Power and Energy Conference*. 2016.
- Pepin, Vanessa. "Personal communication between Rob Penney, WSU Energy Program, and Vanessa Pepin, Technical Support for Sinopé." December 12, 2016.
- Pereault, Francis. "Personal communication between Rob Penney, WSU Energy Program, and Francis Pereault, Tech Support, Stelpro." December 2016.
- Pinkston, Debbie. "Personal communication between Rob Penney, WSU Energy Program, and Debbie Pinkston, King Electric." June 2017.
- Raymond, Sebastian. "Personal communication between Rob Penney, WSU Energy Program, and Sebastian Raymond ." *CaSa*. May 2017.
- Robison, David and Howard Reichmuth. "Comfort STAT Program Evaluation Final Report." *Steller Processes, Inc. and West and Company for the Eugene Water and Electric Board*. May 24, 2002.
<https://nwcouncil.app.box.com/s/56cw7undudmqye97vo1a21z1aowc3ntl>.
- Romberger, Jeffrey. "The Challenge of Vapor-Diaphragm Thermostat Retrofits in Existing Multifamily Buildings." *2008 ACEEE Summer Study on Energy Efficiency in Buildings*.
http://aceee.org/files/proceedings/2008/data/papers/1_177.pdf, 2008.
- RTF. "Regional Technical Forum April 19, 2016 Meeting Minutes." April 19, 2016.
<https://nwcouncil.app.box.com/s/j03rhv4d43aimm4tzil29xneptvhnav>.
- . "Summary of Measure Assessment Methodology and Data Sources for Connected Thermostats, Version 1.2." *NW Council Regional Technical Forum*. April 5, 2017.
<https://nwcouncil.app.box.com/v/ResConnectedTstatsv1-2>.

- Seattle City Light. "Multifamily Space Heat Thermostat Metering Study, Phases 1 and 2." *Seattle.gov*. December 2006. http://www.seattle.gov/light/Conserve/Reports/Evaluation_11.pdf .
- Selby, Jordan. "Personal conversation between Rob Penney, WSU Energy Program, and Jordan Selby, Technical Support, Cadet." *Cadet*. 2017.
- Sinopé. *Online Resources*. December 2016. <http://www.sinopetech.com/en>.
- Stelpro. *4000 W KI Thermostat for the Smart Home - Z-Wave*. December 2016. <http://www.stelpro.com/en-US/4000-w-ki-thermostat-smart-home-z-wave>.
- Stewart, Clint. "Personal communication between Rob Penney, WSU Energy Program, and Clint Stewart, Energy Efficiency Marketing Manager at Puget Sound Energy." May 2017.
- Storm, Poppy et al, Ecotope Inc. "Residential Building Stock Assessment: Manufactured Home Characteristics and Energy Use." *NEEA.org*. January 30, 2013. <http://neea.org/docs/default-source/reports/residential-building-stock-assessment--manufactured-homes-characteristics-and-energy-use.pdf?sfvrsn=8>.
- Walker Technologies. *MyHomeHeat - Home Control Systems*. January 2017. <http://www.walkersys.com/wiredproducts/homecontrol.html> .
- Walker, Allen. "Temperature Measuring in Smart Controllers." *Automated Buildings*, September 2013.
- . "Personal communication between Rob Penney, WSU Energy Program, and Allen Walker, President of Walker Technologies Corporation." January 10, 2017.
- Wilson, Brad. "Personal communication between Rob Penney, WSU Energy Program, and Brad Wilson, Vice President, King." *King Electric*. June 2017.

Appendix C. Research Studies

Eugene Water and Electric Board (EWEB)

In 2002, two consulting firms (Stellar Processes, and West and Company) performed an impact evaluation of EWEB's Comfort STAT program. This program replaced all bimetallic thermostats with electronic thermostats (either programmable or not) in over 2,500 homes between 1999 and 2002. On average, five thermostats were replaced per home. As of September 2000, program participants included 310 single-family or duplex homes, and 243 multifamily homes. Low-income families accounted for 80% of the multifamily units, and about half of the duplex and single-family homes. Energy education offered to homeowners focused on how to use the thermostats.

Installed costs averaged \$38 for non-programmable models and \$72 for programmable models. Energy savings for participants with programmable thermostats were 1,475 kWh/year; this was attributed, in part, to a smaller deadband. Homes in the control group experienced a reduction in energy use of 380 kWh/year. Correcting for the effects of a rise in energy prices during that period, energy use in the research homes should be reduced to 1,095 kWh/year (from the observed 1,475 kWh/year). The normalized annual consumption before the study was listed as 11,548 kWh. The annual savings would then be roughly 9.4%.

Evaluators calculated the program cost effectiveness for a 15-year levelized cost (the cost of installing and operating equipment over its expected life) at 2.3 cents/kWh. They found that this program could be more effective in achieving energy savings by making sure customers are home during the installation, which apparently was not always the case, and engaging housing agencies to provide training materials to new tenants to ensure more persistent energy savings. The evaluators also suggested that the utility encourage manufacturers to produce products that are easier to use and quieter to address two of the occupant's primary complaints (Robison 2002).

University of Quebec at Trois-Rivieres

University of Quebec at Trois-Rivieres estimates that a programmed set point resulted in a 4% reduction in energy use (842 kWh/week down from 874 kWh/week) (Guzmán 2016). The study modeled and simulated common Canadian home heating systems using MATLAB/lowest peak power. It evaluated centralized and baseboard systems in terms of their impact on peak power and energy consumption. Thermostats studied include bimetallic and electronic models with long (5-20 minutes) and short (15-20 seconds) control intervals or cycles.

Hydro Quebec

Hydro Quebec estimates that homeowners that installed at least one programmable thermostat reduced their heating energy use by 434 kWh, a 3.6% savings. Estimates were made using regression analysis of large samples. However, they also noted how challenging it is to accurately estimate reductions in heating energy use based largely on billing analysis due to variations in weather and other factors (Michaud 2009).

The Institute of Research at Hydro Quebec (IREQ-LTE)

IREQ-LTE performed a study (Fournier 2016-1) of the demand response potential of connected thermostats controlling electric resistance heaters. It was performed at the MEEB facility, which consists of identical detached all-electric homes at the Laboratory of Energy Technologies site in Shawinigan, Quebec. The homes were not occupied or furnished during the study period, solar gain was blocked, and each home included a basement.

The first part of the study focused on the impacts of preheating and set point ramping to create advanced set point modulation. The second part focused on controlling various sets of baseboards in the homes to determine the optimum fraction and selection strategy to explore the potential to minimize the number of baseboards for which bimetallic thermostats needed to be replaced with more costly line-voltage connected thermostats.

Each room was equipped with a line voltage connected thermostat controlling an electric baseboard heater. Heating demand, air temperature, and mean radiant temperature were measured at 15-minute intervals. Responses to two daily peak demand events (6 to 9 a.m. and 4 to 8 p.m.) were measured for three days.

For Study 1, using a simple strategy, the set point was instantaneously lowered by 3.6°F at the start of a simulated peak demand event and raised back up at the end of that period. Using a more advanced strategy, the set point ramped up 1.8°F starting two hours prior to the event. At the beginning of the event, it was ramped down to 1.8°F below the starting set point. At the end of period, the set point was ramped back up to the starting value over the course of an hour.

Heating demand was zero for almost an hour at the beginning of each period, then slowly returned. At the end of the period using the simpler strategy, demand spiked up to 11.6 kW, compared with the baseline of 4 kW. Since this could create another peak demand for the utility, the utility could end the event at slightly different times for different groups of houses. Using the advanced strategy, heating demand peaked about an hour prior to the event, and the spike following period was only up to 5.5-7 kW.

The simple strategy achieved greater heating demand reduction: an average 74% reduction compared to roughly 56% for using the advanced strategy.

Vertical air temperature differences only exceed thresholds for ASHRAE 55-2013 briefly using the simple strategy in above ground rooms and not at all in the basement. Similarly, operative temperatures only exceeded ASHRAE 55-2013 for the simple strategy.

Overall, the simple strategy resulted in 20-27% greater demand reductions than the advanced strategy but had greater impacts on occupant comfort. The author has found that occupants of baseboard-heated homes generally expect greater levels of comfort, so this could be an issue with widespread adoption.

For Study 2, heaters were controlled in six combinations of two or three rooms. A two-hour preheating period was used during the morning event but not the evening events. Temperatures were changed instantaneously rather than ramped.

The study found that heat generally flowed from certain rooms (masters) to other rooms (slaves) when no interior doors precluded heat migration, apparently because the master rooms had relatively more heating capacity relative to the heating needs of these spaces. As a result, controlling master rooms had a larger impact on demand reduction than controlling slave rooms. Interestingly, the status of masters or slaves for various rooms was different from one house to the other, even though the two houses were built identically. It is, therefore, difficult to determine which rooms to control. The author recommends controlling all thermostats in open spaces to eliminate the chance of relying on the control of a slave room, prioritizing rooms with the largest areas, and prioritizing basement rooms over above-ground rooms if the basement is used as a living space (Fournier, 2016).

Appendix D. Product Details

Line-Voltage Thermostats

CaSA

The CaSA (pronounced “Kaysah”) Caleo thermostat offers remote control through a smart phone app, seven-day programming, data encryption, and space humidity monitoring. It can control baseboard heaters but not fan-forced heaters or radiant floors because they lack the longer control intervals and temperature probes needed for these applications.

Caleo connects with hundreds of home and personal electronic devices using IFTTT. Four of these devices related to occupancy sensing are the Nest thermostat, Fitbit, Gmail appointments, and Smart Phone geolocating. If a Nest thermostat, which has a “Home or Away” determination, is controlling a central HVAC system, the CaSA Caleo trusts that Nest’s occupancy sensor, geolocating, and self-learning programming are more accurate, and allows all heating to be controlled directly by the Nest. When Fitbit senses a sleeping state, programming is overridden to set the temperature back. Gmail appointments cause setbacks because it assumes the occupant is not home. Smart Phone Geolocating defines a local area (a “geofence”) that may include home, work, etc. If a smart phone reports that the occupant has left that area, the thermostat will switch to the long-term away setback.



If a Nest thermostat (which may be used for the great room while baseboards are used in remote bedrooms) indicates the homeowner is not home, a Gmail calendar indicates a scheduled meeting elsewhere, an iPhone indicates being out of town, or a Fitbit reports that the homeowner is still sleeping, the CaSA thermostat can override programming accordingly (Desautels 2016).

Empowered Homes



The Mysa thermostat was released in early 2018. It can control baseboards and fan-forced heaters. Each thermostat has a Wi-Fi chip for remote control using WPA-2 encryption. It uses smart phone geolocating to determine if occupants are home. It uses weather data to calculate how long each room takes to warm up. Occupants can program the departure and return for an upcoming vacation. It generates detailed reports on energy use and suggestions for saving more energy. It can interface with Apple HomeKit, Amazon Echo, Google Home, Amazon Alexa, Samsung SmartThings, and Wink Versa, using APIs (application program interfaces) (Empowered Homes 2017) (Green 2017).

King Electric

King Electric offers ten electronic line-voltage thermostats with various levels of programmability and communications protocols. These thermostats can control up to 3,840W of heaters at 240V, and can be used on baseboard, fan-forced, and radiant electric heaters. The thermostats have a sample rate of 1 minute and a delay of 2 to 3 minutes, but claim deadband of 1°F or less.

The Atmos offers both Wi-Fi and Bluetooth-enabled series. Model (ATMOZ1/2-240-WIFI) uses Wi-Fi and offers smart phone control and up to six programmable periods per day. A “Boost Mode” can extend a programmed period up to 3 additional hours, without changing the program schedule. Atmos Bluetooth electronic programmable thermostat uses Bluetooth with a smartphone. Its range is 30 to 60 feet depending on wall construction.



The Atmos smart phone app can control multiple thermostats. The control interval varies from one to four minutes, depending on the temperature drop, and is the same for baseboards and fan-forced heaters. The interval is increased to 10-15 minutes to control fan-forced heaters.

Internal heat compensation is controlled well in these thermostats, and users may adjust the temperature displayed to manually compensate for droop.

King Electric has two models focused on multifamily, college dorms, and motels that provide features to ensure energy savings in the face of wasteful occupant habits. K202E, the TEMP 360° temperature lock, for property managers (75 degrees max).

The Autonomous Dual-time Stat offers a minor setback that drops the set point to 58°F, 62°F, or 65°F after 1 to 16 hours regardless of occupancy. After 12 to 60 hours without a manual temperature adjustment (taken as an indication of vacancy), a major setback drops the temperature to 55°F, 52°F, or 40°F. Their Window Watcher model has two remote window/door sensors and automatically drops the set point to 40°F when either is open. It also has an occupancy sensor with a 1- to 6-hour delay to set back temperature to 58°F when the space is unoccupied. Has 7-day programming or a simple non-programmable model.

Simplestat has three pre-sets and manual operation so complex programming isn't required. The default setting is 70F during the day, 60F when sleeping, and 55F when away (King 2017) (Wilson 2017).



Nuheat

Nuheat’s Signature thermostat is designed specifically to control electronic resistance flooring systems. While it is ideal for Nuheat flooring systems, it is also compatible with any electric floor heating system, although there may be variation in temperature readings (Nuheat 2017).

It connects to Wi-Fi and offers remote access via smartphone apps or web browser; connects to local outdoor temperature and daily weather forecasts; and reports hourly, daily, weekly, and monthly energy usage. As of 2016, it can connect to a Nest thermostat to add occupancy sensing (Nuheat 2017).

Sinopé

Sinopé (pronounced “sinnopay”) offers two lines of line-voltage connected thermostat products – thermostats with ZigBee that work with Google Assistant and Alexa via SmartThings and Control4, and thermostats that are web programmable using neviweb (RF). Product sheets call the Zigbee line “Smart” thermostats, while the other is called “Web Programmable”. Per the definitions in this report, the latter is considered connected.

Both lines offer remote control using smart phones, tablets, or computers with dual layer data encryption. Hourly energy consumption reports for the past day and daily reports for the previous month can be generated, and seven-day programming with up to six periods a day may be scheduled. In addition, there is an “away” mode.



The RF neviweb products (TH1120RF-4000/3000) require a Web interface at extra cost. The Zigbee version requires a Zigbee compatible hub.

A new double-pole thermostat (TH1500RF) using Neviweb and controls 3600W.

In addition to controlling electric baseboard heaters, Sinopé also offers products that control:

- Baseboard heaters in public spaces using a model that can only be programmed remotely and does not display space temperature
- Fan-forced heaters (wall-mounted, forced air such as Cadet) using their line voltage thermostat set to long (15-minute) rather than the standard short (15-second) control intervals
- Radiant floors with their thermostat that protects against fault hazards with GFCI (ground fault circuit interrupter) and can use feedback from air or floor temperature (using sensors)
- Baseboard heaters using unconnected and non-programmable electronic models for people who are less comfortable with more advanced communications technologies

Note that almost identical thermostats are sold under the Ouellet brand. The Ouellet’s model is limited to 2,750W (rather than 4,000), they cannot connect to home automation systems, they do not offer programming customization for a fee (as Sinopé does) and are only sold through electrical contractors (Hervieux 2017).



Stelpro

Stelpro Ki thermostats require a home automation system utilizing Z-Wave or ZigBee communication. With ZigBee, it can currently only connect to Vera systems, but with Z-Wave it can connect to Vera, Wink, Nexia, and Samsung's SmartThings. Fan-forced heaters can be controlled using ZigBee but not Z-Wave. The default for fan-forced heaters is 90 seconds, but can be programmed to increase to up to 5 minutes. There are advantages to this for someone who already has or wants to install a home automation system, but it is not a simple replacement for a bimetallic thermostat.

Stelpro's new Maestro thermostat, planned for 2018, includes geofencing capabilities. Maestro works with electric baseboards, convectors and fan heaters.

Walker Technologies

Walker Technologies has a product line that includes a central controller that connects to the Internet through the home's Wi-Fi for remote control and acts as a programmable hub connected to thermostats via ZigBee. The thermostats sense temperature and motion, and allow local control with schedules and minimum and maximum temperature limits set at the central controller, which can average temperature readings from multiple remote thermostats.



The built-in occupancy sensor has a 5-meter range, and requires motion detection from two different thermostats. The default vacancy sensor setback delay is 12 hours to ensure vacancy, but this can be adjusted. Users can program setbacks for short-term and long-term vacancies. Adding wireless remote thermostats improves motion sensing, as well as allowing local override of set points as long as it is within the main control's limits. The company is currently focusing on a multifamily application in Toronto with 3,000 zones (Walker 2017).

Appendix E. BPA Product Readiness Levels

Market/Commercial Readiness	Level 1	Level 2	Level 3	Level 4	Level 5	
<i>supply chain maturity/product availability</i>	Not commercially available or limited, pre-commercial availability	Commercially available outside of NW; Requires special order in NW	Commercially available in NW from 1 manufacturer through standard channels.	Commercially available in NW from at least two manufacturers; Stocked throughout region	Commercially available from 2+ manufacturers, well developed supply chain; Widely and easily available	
<i>presence of market failures/lack of market maturity</i>		Existing market not ready, but similar to other successfully transformed markets warranting further efforts; Limited market awareness	Limited market research suggest market failures/barriers and opportunities to intervene; Growing market interest	Market characterization provides details on barriers and opportunities, some barriers already being addressed; Growing desire for product	Market is starting to function well and appears on path to sustainable, financial viability	
Product Performance (based on BPA's Measure Readiness Levels)	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
<i>Energy savings viability</i>	Concept not validated	Concept validated	Limited Assessment	Extensive Assessment	Comprehensive Analysis	Approved (by whom? RTF?)
<i>Fitness for use</i>	Claims of energy savings may not be credible due to lack of documentation or validation by unbiased experts.	An unbiased expert has validated efficiency concepts through technical review and calculations based on engineering principles.	An unbiased expert has measured technology characteristics and factors of energy use through one or more tests in typical applications with a clear baseline.	Additional testing in relevant applications and environments has increased knowledge of performance across a broad range of products, applications, and system conditions.	Results of lab and field tests have been used to develop methods for reliable prediction of performance across the range of intended applications.	Protocols are established and approved (by reaching RTF "approved" level?)
<i>RTF measure status(if applicable)</i>		Planning	Planning	Provisional	Provisional	Proven

Program Readiness	Level 1	Level 2	Level 3	Level 4	Level 5	
<i>Cost effectiveness</i>	N/A	Not cost effective, but preliminary analysis shows a pathway to CE	Not cost effective but shows pathway to CE with higher volumes, more competition, improved technology	Marginally at cost effective levels	Cost effective	
<i>Program delivery/interventions</i>	No program design	Limited program design	Preliminary program design, small scale pilots	Program design complete, larger scale pilots underway	Ready for full-scale programs.	
<i>Risk Assessment (Technical, Market, Program, Regulatory)</i>	No risk assessment	Limited risk assessment	Preliminary risk assessment complete - major categories of risk understood	Well-developed risk assessment - no major unresolved risks	Periodic risk assessment process in place.	